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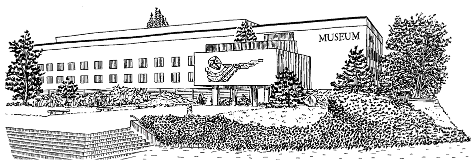

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New biostratigraphic data from the Callovian-Oxfordian La Manga Formation, Neuquén Basin, Argentina: Evidence from an ammonite condensed level

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Abstract
The La Manga Formation constitutes most of the sedimentary record of the Callovian-Oxfordian in the Neuquén Basin. This stratigraphic unit represents the middle part of the Lotena Mesosequence, which is dominated by carbonates with interbedded shales, marls, and occasional sandstones. Based on detailed stratigraphic work in the stratotype section (La Manga Creek, Mendoza), the depositional environments and the sea-level history of the La Manga Formation have been interpreted. Petrographic and field observations led to identification of nine facies distributed in two informal units. Unit 1 was deposited on a outer ramp setting, while deposition of unit 2 took place in the intertidal-supratidal environments. A condensed level close to the base of unit 1 has yielded *Rehmannia* sp., *Rehmannia* cf. *paucicostata* (Tornq.) and *Homoeoplanulites* sp., from the Lower Callovian Bodenbenderi-Proximum Zones, and *Peltoceratoides* sp. and *Rursiceras* sp. from the Upper Callovian and also in the Lower Oxfordian *Peltoceratoides*-*Parawedekindia* Zone. The condensed level is overlain by a Middle Oxfordian succession characterized by *Perisphinctes* (?*Arisphinctes*) sp., *Perisphinctes* (?*Kranaosphinctes*) sp., *Mirosphinctes* sp., *Perisphinctes* (?*Antilloceras*) cf. *prophetae* Gygi & Hill., *Perisphinctes* (*?Otosphinctes*) sp., *Perisphinctes* (?*Subdiscosphinctes*) sp., and *Perisphinctes* (?*Kranaosphinctes*) cf. *decurrens* (Buck.) of the *Perisphinctes*-*Araucanites* Zone, which was correlated with the upper part of the Cordatum Standard Zone to the Transversarium Standard Zone, and probably to the lower part of the Bifurcatus Standard Zone. Unit 2 has yielded small *Mirosphinctes* sp., indicating an Oxfordian age. The sharp contact between the outer ramp facies of unit 1 and the overlying intertidal-supratidal facies of unit 2 can be interpreted as the result of an abrupt fall (forced regression) of the relative sea level during the end of Middle Oxfordian or Upper Oxfordian. These results could be used for comparison with other localities in the Neuquén Basin providing additional data for Lower Callovian-Middle Oxfordian deposits.

Keywords
Carbonate ramp, forced regression, Jurassic ammonites, Neuquén Basin.

I. INTRODUCTION

During the Callovian-Oxfordian times in the Neuquén Basin, a widespread carbonate deposition resulted in vertical and lateral mosaics of shallow-water facies, adjacent to deep-water calcareous deposits. All these carbonates today form the so-called La Manga Formation (Lotena Mesosequence)(Legarreta, 1991; Legarreta & Uliana, 1996; Palma *et al*., 1997, 2007, 2009; Lo Forte & Palma, 2002), a wide carbonate ramp exceptionally exposed in west-central Argentina. Carbonate ramps respond in complex ways to sea-level changes and tectonics (Burchette & Wright, 1992), and complex facies distribution is inherent to this unit, being largely controlled by different depocentres of the Neuquén Basin (e.g., Palma *et al*., 2007, 2009, 2010b). However, detailed correlation and paleogeographic reconstruction of this ramp are difficult due to the lack of precise biostratigraphic controls.

The aim of this study is to provide new information about the palaeoenviromental evolution of La Manga Formation in its type locality. Of specific interest is the presence of a condensed stratigraphic level that includes several ammonite biozones, and which provides new insight into temporal resolution of the Lotena Mesosequence. New biostratigraphic data include ammonites of Early Callovian to Middle Oxfordian age. The ammonite specimens are housed in the collection of the Museo de Ciencias Naturales de La Plata (División de Paleozoología de Invertebrados), Argentina (MLP 32584-32618).

II. STRATIGRAPHIC FRAMEWORK

The Neuquén Basin, located at the west margin of the South American platform, is limited by a magmatic arc to the west and a tectonic foreland to the east. The foreland

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consists of the Sierra Pintada belt to the northeast and the North Patagonian massif to the south. The Neuquén Basin is a typical retro-arc basin that developed to the east of the Cordillera Principal between 36ºS and 39ºS. The most important papers describing the geologic setting of the region include those of GROEBER (1946), DIGREGORIO & ULIANA (1980), GULISANO *et al*. (1984), MITCHUM & ULIANA (1985), among others. LEGARRETA & GULISANO (1989) described four tectonic episodes of basin development: 1- rifting (Upper Triassic-Lower Jurassic), 2- thermal subsidence (Lower Jurassic-Upper Cretaceous), 3- magmatic subsidence and loading (Upper Cretaceous-early Tertiary) and 4- Andean tectonism (early Tertiary-Quaternary).

The basement consists of early Palaeozoic to Late Triassic metamorphic, plutonic, volcanic, and sedimentary rocks. GROEBER (1946) identified three depositional cycles: Jurásico, Ándico and Riograndico. LEGARRETA & GULISANO (1989) agreed generally with the validity of the GROEBER's cycles, and emphasized the importance of eustatic variations in the development of depositional sequences. In the Neuquén Basin different depocentres resulting from the basin evolution were recognized (MANCEDA & FIGUEROA, 1995; TANKARD *et al*., 1995). One of these is the Atuel depocentre, located in the northern sector of the basin (GIAMBIAGI *et al*., 2008) (Fig. 1).

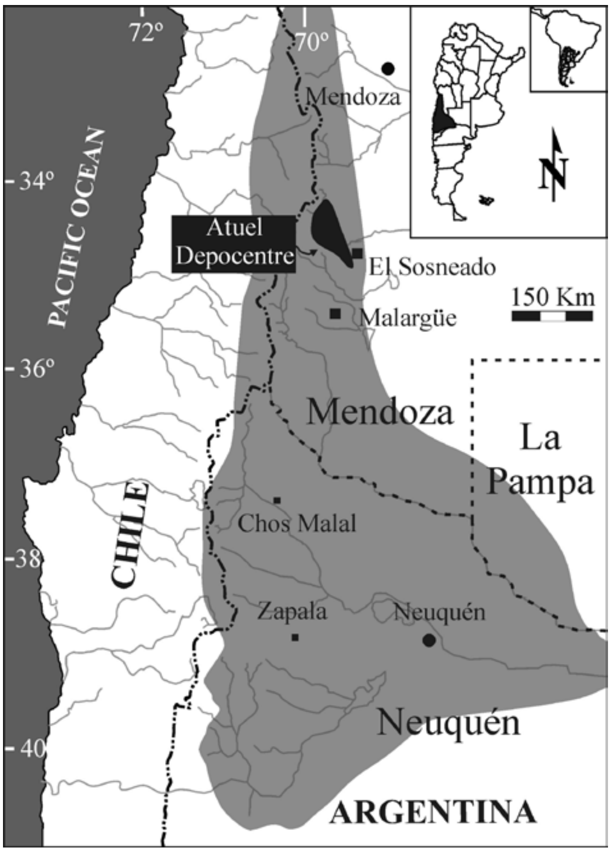

Fig. 1: Location map of the Neuquén Basin with indication of the Atuel depocentre.

The Jurassic sequences in the Atuel depocentre are part of the Lower Supersequence of LEGARRETA & GULISANO (1989), which includes three mesosequences: Precuyo, Cuyo and Lotena. The Precuyo Mesosequence (Upper Triassic-Sinemurian) consists of non-marine siliciclastic and volcanic deposits. The Early Sinemurian to Early Callovian deposits are known as Cuyo Mesosequence (LEGARRETA & GULISANO, 1989; LANÉS *et al*., 2008), composed mainly of marine siliciclastic deposits. The Lotena Mesosequence comprises five depositional sequences that include marine and continental facies (Lotena Formation), carbonate deposits (La Manga Formation), and evaporite deposits (Auquilco Formation). The age of the Lotena Mesosequence was considered as Middle Callovian to Late Oxfordian-Kimmeridgian (LEGARRETA & GULISANO, 1989) (Fig. 2).

III. STRATIGRAPHIC SUCCESSION

The La Manga Formation constitutes most of the sedimentary record of the Callovian-Oxfordian. It shows several transgressive pulses and represents a clear craton-ward onlap resulting in a starved basin axis and depositional profiles lacking steep slopes as result from rapid expansion on the broad depositional area of the Earlier Callovian sediments (LEGARRETA, 1991).

Analysis of the lithological characteristics and the fossil assemblages in each bed of the Callovian-Oxfordian transitional interval resulted in a detailed stratigraphic framework for the type locality of this lithostratigraphical unit. The analyses were aimed at finding paleontological evidence for the presence of a condensed level. A representative section of the La Manga Formation was thoroughly studied (Fig. 3).

The studied section is located in the La Manga creek, 25 km west of the small town of El Sosneado (Fig. 1). From a paleogeographical point of view, this area corresponds to the so-called Atuel Depocentre within the Neuquén basin (Fig. 1). The stratigraphical succession of the La Manga Formation represents the middle part of the Lotena Mesosequence, which is mainly constituted by carbonates with interbedded shales, marls, and occasional sandstones.

Studies of the La Manga Formation have been largely focused on its lithostratigraphy, biostratigraphy, and palaeontology (GROEBER *et al*., 1953; STIPANICIC, 1965, 1996; LEANZA, 1981; RICCARDI, 1984, 1992, among others), as well as on sedimentological interpretations (LEGARRETA, 1991; LO FORTE & PALMA, 2002; PALMA *et al*., 2007, 2009; BRESSAN & PALMA, 2010) and diagenetic aspects of the succession (PALMA *et al*., 1997). Detailed sedimentological and biostratigraphic studies allowed us to recognize facies and sedimentary environments not previously described for this unit, as

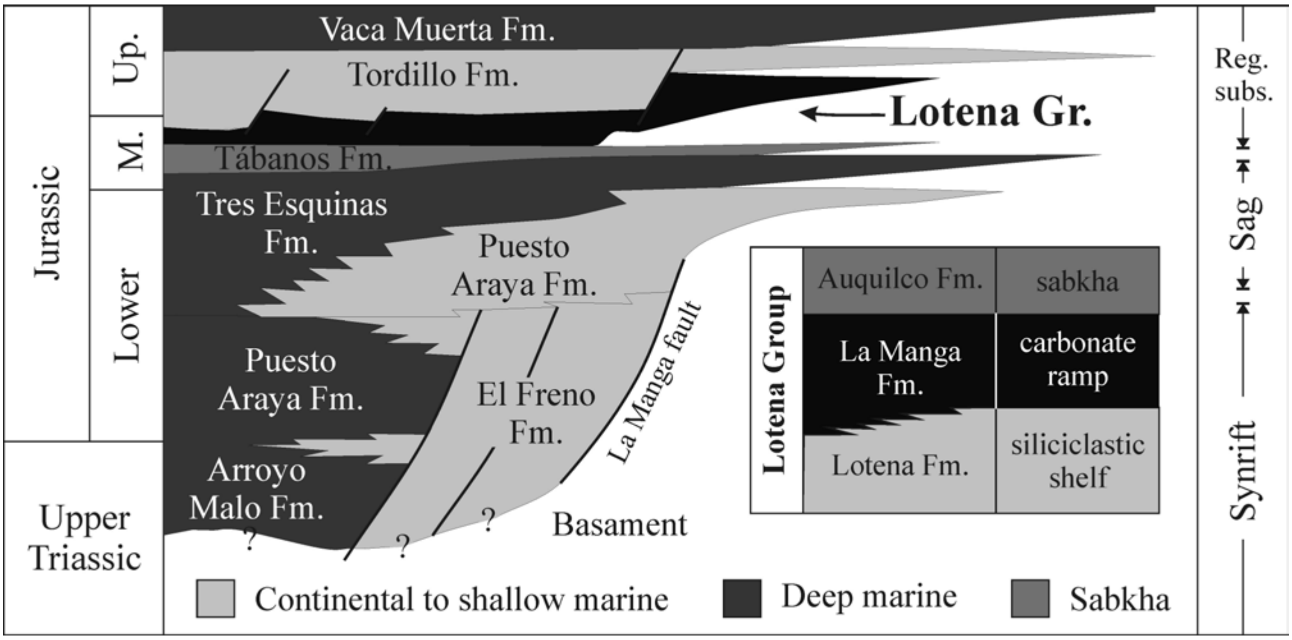

Fig. 2: Jurassic stratigraphic framework of the Neuquén Basin at Atuel depocentre (modified from Giambiagi *et al*., 2008).

well as its vertical evolution, that is recognized in different places beyond the Atuel depocentre, such as Las Yeseras, Codo del Blanco, and Potimalal area. Recently, Palma *et al*. (2011) made comparisons among the sedimentary facies in different outcrop areas, recognizing the presence of turbidite facies for the first time.

IV. SEDIMENTARY FACIES AND DEPOSITIONAL SYSTEM

The La Manga Formation is well exposed in its type locality, where it reaches 53 m in thickness and shows a variety of carbonate deposits. Nine main facies were recognized, which characterize outer ramp and peritidal settings. On the basis of the facies associations, the succession was divided into two informal units (Fig. 3): a lower (unit 1) formed by outer ramp facies and an upper one (unit 2) comprising intertidal and supratidal facies.

Unit 1: Outer ramp

Unit 1 is 46 m thick and consists of centimetre- or decimetre-scale beds (usually 5-35 cm) of argillaceous mudstones, wackestones, and occasionally packstones commonly interbedded with thinly laminated dark green marls and pale olive to light olive grey shales, rich in organic matter (Palma *et al*., 2010a) (Fig. 4A). Carbonate beds are usually massive, occasionally showing normal grading. The lower contacts are generally sharp and planar, and occasionally show erosive features, whereas the upper contacts range from sharp to gradational.

Mudstone facies, frequently argillaceous, are usually split into 5-20 cm thick beds. They contain scattered radiolarians, sponge spicules and peloids (Fig. 4B). Subangular to angular silt-sized quartz clasts are common. The clay-rich matrix of the rock shows flattened amorphous organic matter. Authigenic pyrite crystals are also frequent in this facies.

Wackestone facies occurs in beds with thickness ranging from 7 to 20 cm. The beds are interbedded with massive or laminated marls or shales, and show either sharp or erosional bases. Limestones show, from base to top, a gradational change from a massive basal layer to a distinctly densely laminated upper horizon, rich in ostracod shells and organic matter (Fig. 4C).

The wackestones include radiolarians, small disarticulated and fragmented gryphaeoid shells, scattered forams, as well as fragments of echinoids and sponge spicules (Fig. 4D). Peloids, small intraclasts, subangular to angular silt size quartz and feldspar grains, as well as mica flakes are common. Sometimes the top of the beds show *Thalassinoides*.

Packstone facies occurs in beds with thickness ranging from 5 to 20 cm. Fine-grained peloidal-oolitic laminae appear interbedded with more dense microsparitic matrix laminae. Ooids have undergone micritization (types 3 and 4 of Strasser, 1986). Echinoderm fragments, disarticulated ostracods and possible subcylindrical dasycladacean algae fragments were observed. Subangular to angular silt size quartz and feldspar clasts are common.

Shale facies comprises unfossiliferous, black to dark-grey green, laminated shale in beds between 4 and 27 cm thick. The shales are composed of carbonate and clay-

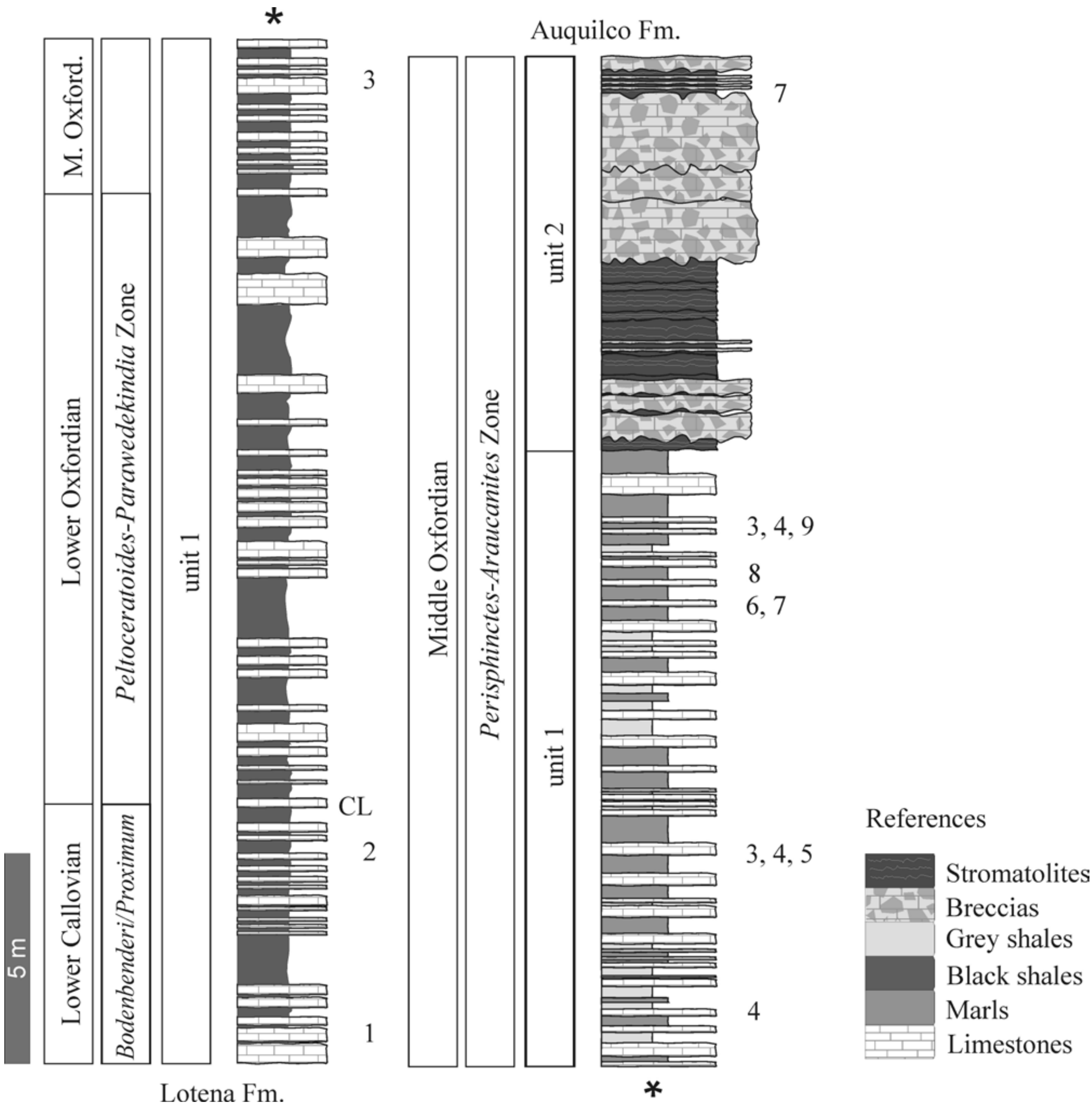

Fig. 3: Simplified lithological log of the La Manga Formation at La Manga creek, and ammonite distribution: (1) Perisphinctidae indet., (2) *Rehmannia* sp., (CL: condensed level) *Rehmannia* cf. *paucicostata* (TORNQ.), *Homoeoplanulites* sp., *Peltoceratoides* sp., and *Rursiceras* sp., (3) *Perisphinctes* (?*Arisphinctes*) sp., (4) *Perisphinctes* (?*Kranaosphinctes*) sp., (5) *Perisphinctes* (?*Antilloceras*) cf. *prophetae* GYGI & HILL., (6) *Perisphinctes* (?*Otosphinctes*) sp., (7) *Mirosphinctes* sp., (8) *Perisphinctes* (?*Subdiscosphinctes*) sp., (9) *Perisphinctes* (?*Kranaosphinctes*) cf. *decurrens* (BUCK.)

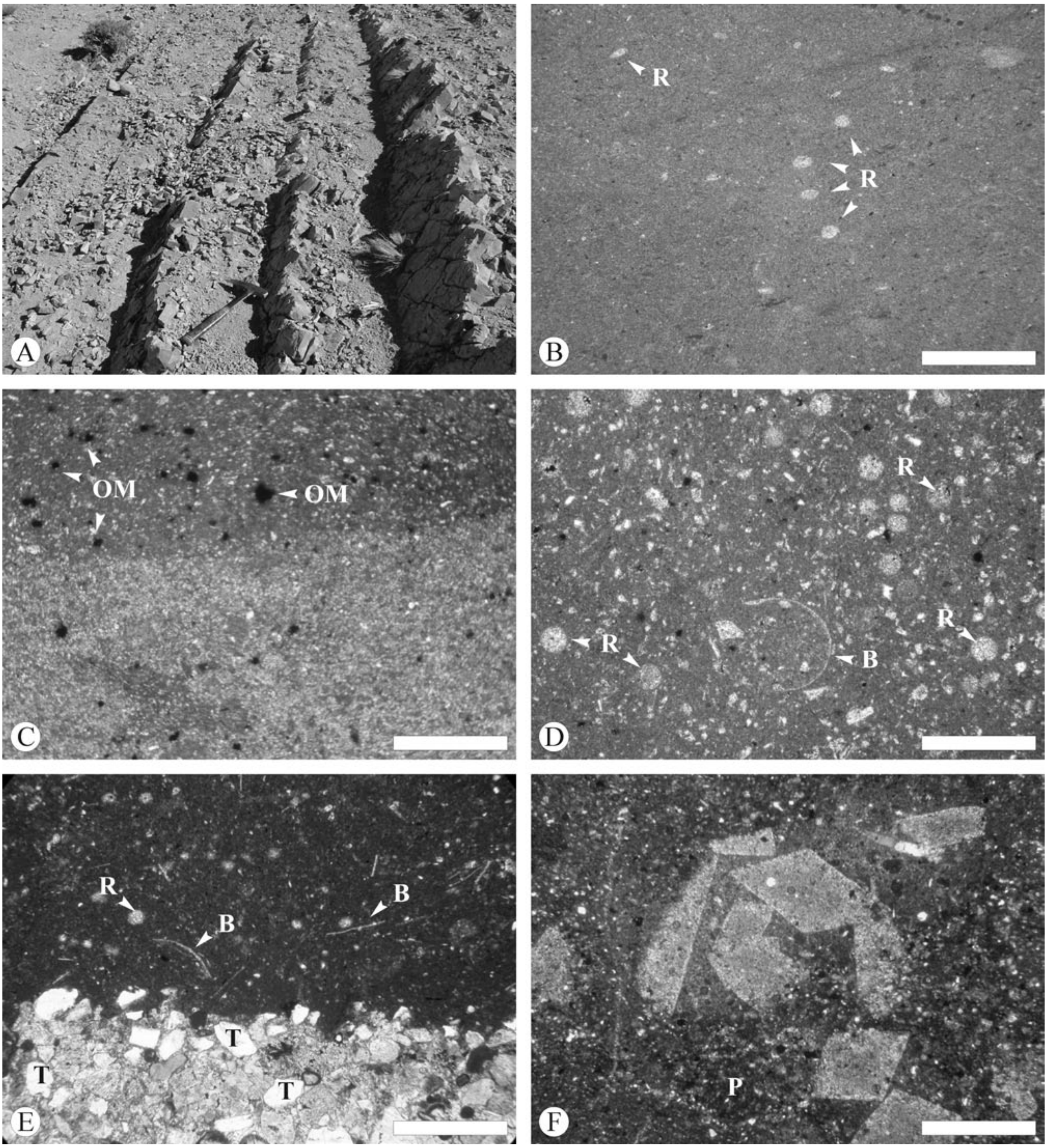

Fig. 4: **A**. View of the outcrop section (unit 1) showing the rhythmic bedding of limestones and marls. **B**. Radiolarian mudstones. **C.** Typical grading of wackestone with terrigenous material and disseminated organic matter (OM). **D**. Bioclastic wackestone with abundant radiolarians (R), thin bivalves (B) and terrigenous materials. **E**. Fine-grained terrigenous packstone changing abruptly into bioclastic wackestone (T: terrigenous material; R: radiolarians; B: thin bivalves). **F**. Wackestone with pseudomorphs of evaporite crystals. Additionally smaller micritic intraclasts and fined-grained terrigenous material. Scale bar: 0.5 mm.

rich laminae, dominated by illite, followed by kaolinite and chlorite. Other abundant clay minerals are illite-smectite mixed-layers. TOC values reach up to 1.98% (PALMA *et al*., 2010a).

Marl facies are represented by massive to laminated light brown and light-grey marls. It occurs as 4 to 27 cm thick laterally continuous beds, with planar to slightly irregular surfaces. They are frequently interbedded with limestones and shales. Marls contain centimetre-size nodules of wackestones, and some isolated bivalves (*Gryphaea*).

Thinly laminated facies of microbial origin are also present in this unit. They form 5 to 7 cm thick intervals usually located between Lower Oxfordian mudstones and shales. The lamination is expressed by millimetre scale wavy to crinkly laminae, which are laterally continuous for tens of metres. Scarce horizontal trace fossils are observed. This facies contains disseminated iron oxide micronodules.

Sandstone facies comprises 4 to 23 cm thick fine to medium grained massive beds interbedded with shales, where no fossils have been found so far. Sandstone beds have sharp planar bases that may be smooth. Some beds do not exhibit well-developed grading, but sometimes show narrow sole markings.

The age of this unit is well defined by the ammonite assemblage, which indicates an Early Callovian–Early Oxfordian age for these deposits (PALMA *et al*., 2010b, 2011).

Interpretation: These outer ramp deposits are arranged in decimetre-scale sedimentary cycles. This interpretation is based in the abundance of lamination and high organic matter content in shales and marls which suggests settings below storm wave base (e.g. BURCHETTE & WRIGHT, 1992).

Abundance of lime mud in massive or faintly laminated wackestone and packstone facies (Fig. 4E) indicate low hydrodynamic conditions, as well as the lack of current- and wave-induced structures, supporting the previous interpretation.

The high organic matter content suggests high organic productivity or good preservation, related with reducing conditions. Iron minerals content in mudstone facies and in microbial laminae suggests the activity of anaerobic bacteria that might have produced strong reducing conditions (GERDES & KRUMBEIN, 1987; GERDES *et al*., 2000).

Presence of ammonites, radiolarians and sponge spicules also supports the interpretation of this unit as an open and distal environment. Bioturbation probably reflects the fluctuation between rapid and slow rates of supply of suspended sediment.

The presence of terrigenous material could be related to the input of fluvial currents on the margin of the ramp. Massive sandstones with sharp planar bases and narrow sole markings suggest deposition by fine-grained turbidity currents (PIPER & STOW, 1991; EBERLY, 1991). Size distribution of some allochems, including ooids and dasycladacean algae also supports the resedimentation by fine-grained turbidites. The presence of turbidite bed deposits necessarily implies that some relief existed within the basin, which allows the interpretation of this unit as a distally steepened ramp according to READ (1985) and POMAR *et al*. (2002).

These deposits are abruptly overlain by a succession of about 12 m of unit 2, consisting of planar stromatolites, breccias, flat-pebble conglomerates, and paleokarst breccias.

Unit 2: Inner ramp

The inner ramp deposits are represented by upper intertidal to supratidal facies arranged in centimetre-scale cycles. They start with mudstone-wackestones at the base followed by stromatolites or different types of breccias towards the top, suggesting either temporary emergent conditions or hiatuses indicative of variations in salinity.

Mudstone facies, rich in peloids, shows planar lamination or normal grading on a centimetre-scale. This facies alternates with planar stromatolites or flat pebble conglomerate beds. Mudstone beds, ranging in thickness from 2 to 5 cm, contain pseudomorphs of evaporite crystals.

Wackestone facies consists of sharp or erosional based massive or laminated wackestones ranging in thickness from 6 to 25 cm. They are interbedded with dark grey mudstone or stromatolite facies. Wackestones appear weakly bioturbated and, more rarely, with ripple lamination. Small scoured bases show oncolites, while some tops appear with evidence of subaerial exposition. Scoured bottom and the presence of intraclasts point to an active sediment transport. Similar to the previous facies, the wackestone facies also contains pseudomorphs of evaporite crystals (Fig. 4F).

These lithologies alternate rhythmically with thin flat-pebble conglomerates or carbonate breccias, as well as with planar stromatolites.

Stromatolite facies consists of planar to wavy-laminated stromatolites with microcrystalline calcite (Fig. 5A). Stromatolites form beds from 5 up to 80 cm thick. The microstructure consists of fine filmy laminae sometimes defined by organic inclusions (Fig. 5B). Occasionally, millimetre dome growing on the planar or wavy surface appears truncated by intraclast breccias. Stromatolites commonly contain abundant distinctive features, such as micro-tepees, fenestrae, keystone-vugs, mud-cracks, and sheet-cracks (Fig. 5A). Usually, stromatolites are overlain by breccia facies defining small-scale cycles.

Conglomerates or breccias facies consist of rip-up clasts derived from underlying stromatolites (Fig. 5C). Textures range from clast- to matrix-supported, and thickness varies between 4 to 30 cm. Breccia clasts show orientation from bedding–parallel to random, and imbrications also occur. Conglomerates and breccias are

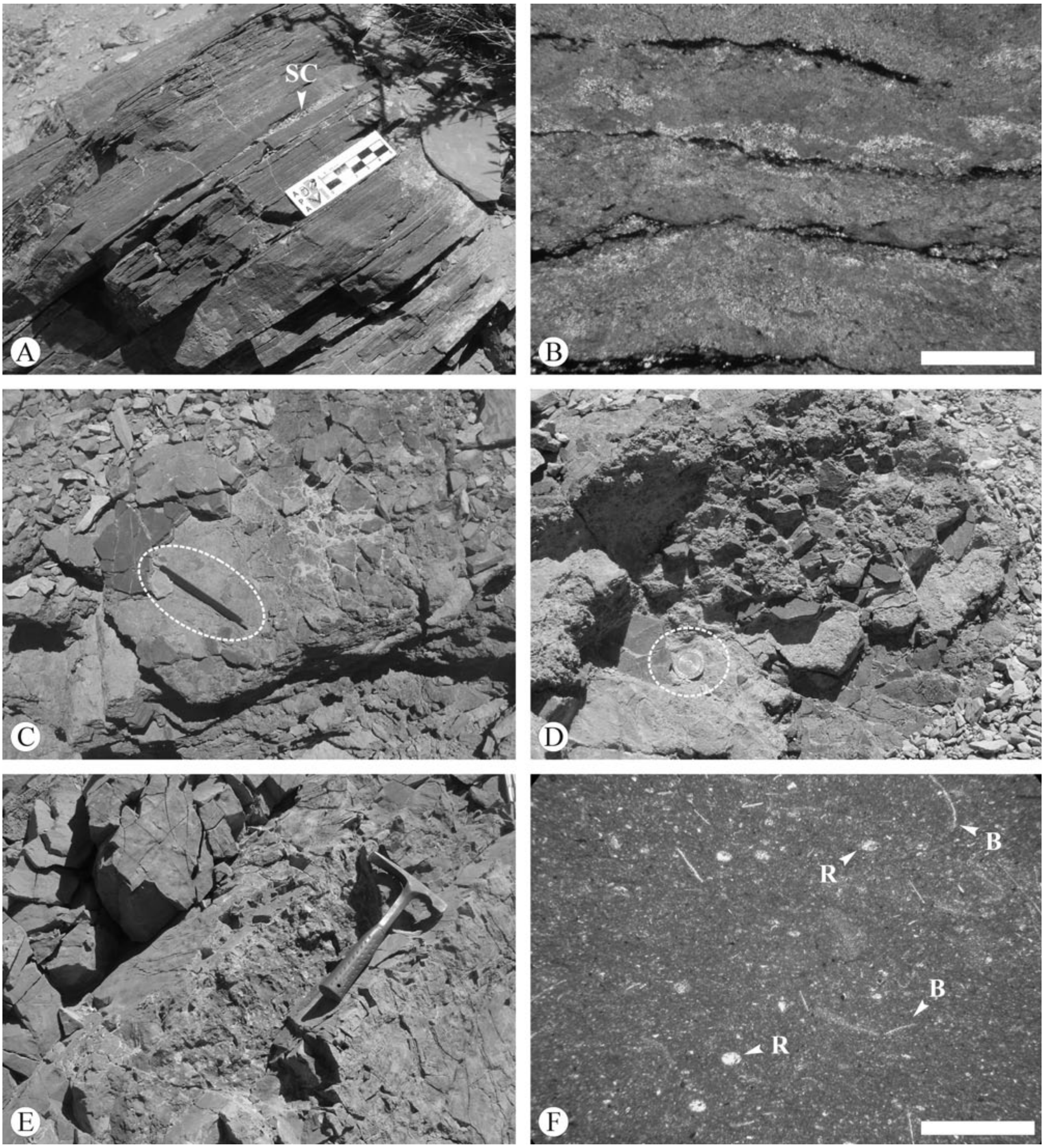

Fig. 5: **A**. Planar to crinkle microlamination from stromatolite unit 2, and sheet crack (SC). **B**. Typical microstructure of alternating dense microbial laminae and microcrystalline groundmass. Scale bar 0.5 mm. **C**. Intraformational breccia with planar and angular stromatolitic intraclasts. Scale pencil 12 cm. **D**. Chaotic breccia displaying random orientation of angular clasts. Coin for scale 2.5 cm. **E**. Top view of condensed level, note bioerosion. **F**. Thin section of the condensed level. Bioclastic wackestone with radiolarian and thin bivalves. Scale bar 0.5 mm

commonly associated with desiccation mud cracks and tepees.

Paleokarst breccia consists of a calcareous matrix-supported, chaotic breccia that shows highly variable textures from silt to cobble size (Fig. 5D). The clasts of breccia are angular with a fitted clast texture to extreme brecciation and chaotically oriented clasts. The petrographical composition of the clasts is consistent with the underlying facies previously described. Its thickness varies between 10 and 30 cm.

Interpretation: Unit 2 deposits are represented by classical peritidal shallowing-upward sequences. The lower part of some small cycles displays dark grey mudstones and wackestones containing scoured bases with gryphaeoids, oncolites and intraclasts, pointing to an active sediment transport.

Incipient fracturing and brecciation textures observed in conglomerates and breccias are interpreted as local autoclastic breccias indicating subaerial exposure of some horizons in the upper intertidal to supratidal settings. These subaerial exposures probably were controlled by sea-level oscillations. Nevertheless, the shoaling-upward trend, regardless of the presence of tepee structures, may be interpreted also as the result of autocyclic mechanisms (e.g. GROTZINGER, 1986; BOSELLINI & HARDIE, 1988; POMONI-PAPAIOANNOU & KOSTOPOULOU, 2008).

The features described for unit 2 are consistent with different episodes of paleokarst development on the intertidal-supratidal setting. Before the beginning of deposition of the Auquilco Formation evaporites, a subaerial episode that resulted in extensive paleokarst surface is recognized.

The sharp contact between the upper intertidal-supratidal facies (unit 2) and the underlying outer ramp facies (unit 1) represents a sharp surface reflecting an outstandingly rapid shallowing trend (forced regression). This can be interpreted as an abrupt fall in relative sea-level during the end of the Middle Oxfordian (or Upper Oxfordian?) in the Neuquén Basin, which probably precluded the deposition of the Auquilco evaporites.

V. BIOSTRATIGRAPHY

The age assignments of the Jurassic series in the Neuquén Basin are primarily based on the ammonite faunas. The age of the La Manga Formation has been controversial since the pioneer works of GERTH (1925), JAWORSKI (1925), GROEBER (1937), and STIPANICIC & MINGRAMM (1953). Ammonites from the La Manga Formation were long regarded as Callovian (GROEBER, 1918, 1933, among others). However, Oxfordian ammonites from the Cordatum-Plicatilis Standard Zones (Lower-Middle Oxfordian) were recognized by STIPANICIC (1951) and STIPANICIC *et al*. (1975) in the La Manga Formation type locality (La Manga creek). This unit was later considered Oxfordian in age (GROEBER *et al*., 1953; STIPANICIC *et al*., 1975; RICCARDI, 1996). Jurassic biostratigraphy of the Neuquén Basin was revised by RICCARDI (1984), RICCARDI *et al*. (1990) and RICCARDI & WESTERMANN (1991). Recently, PARENT (2006) and PARENT *et al*. (2006) proposed an alternative biostratigraphic division based mainly on literature data. A new biostratigraphic chart for the Jurassic ammonite fauna of Argentina has been published recently by RICCARDI (2008) (Fig. 6).

New detailed sedimentary and stratigraphic studies allowed us to present a new record of ammonite faunas of Early Callovian to Middle Oxfordian ages at the type locality of the La Manga Formation. Late Callovian and Early Oxfordian ammonites, poorly preserved, are not usually represented because of the existence of a regional hiatus (RICCARDI, 2008). For this reason, the new data allow us to define temporarily this stratigraphic interval, and, in turn, to clarify some of the issues that have been in discussion for many years.

At 11 m from the base of unit 1 a fossiliferous wackestone 11 to 15 cm thick level appears, interpreted as a condensed bed. The top of this level (Fig. 5E) is marked by intense bioerosion. It yielded *Rehmannia* sp., *Rehmannia* cf. *paucicostata* (TORNQ.) and *Homoeoplanulites* sp., from the Lower Callovian Bodenbenderi-Proximum Zone, and *Peltoceratoides* sp. and *Rursiceras* sp., from the Upper Callovian and the Lower Oxfordian *Peltoceratoides-Parawedekindia* Zone (Fig. 6). In addition to the ammonite fauna, radiolarians and thin-shelled bivalves are very common (Fig. 5F).

The Bodenbenderi-Proximum Zone was correlated by RICCARDI (2008) with the Gracilis/Calloviense Standard Zone (latermost Early Callovian), while the *Peltoceratoides-Parawedekindia* Zone is correlated with the Cordatum and Mariae Standard Zones (Early Oxfordian) (Fig. 6).

That level is overlain by a Middle Oxfordian succession, characterized by *Perisphinctes* (?*Arisphinctes*) sp., *Perisphinctes* (?*Kranaosphinctes*) sp., *Mirosphinctes* sp., *Perisphinctes* (?*Antilloceras*) cf. *prophetae* GYGI & HILL., *Perisphinctes* (?*Otosphinctes*) sp., *Perisphinctes* (?*Subdiscosphinctes*) sp., and *Perisphinctes* (?*Kranaosphinctes*) cf. *decurrens* (BUCK.) from the *Perisphinctes-Araucanites* Zone (Fig. 3).

This zone was correlated by RICCARDI (2008) with the upper part of the Cordatum Standard Zone to the Transversarium Standard Zone, and probably the lowest Bifurcatum Standard Zone (Fig. 6). A similar ammonite association was described by STIPANICIC (1951).

The last 13 m of the studied succession only contains *Mirosphinctes* sp., which could appear in the Middle Oxfordian as well as in the Upper Oxfordian (e.g. MYCZINSKI *et al*., 1998)

Mirosphinctes sp. was also recorded in peritidal storm deposits (similar facies to unit 2) at the Salado River (Los Blancos locality) southward La Manga creek (PALMA & KIETZMANN, 2008).

During the deposition of the La Manga Formation a

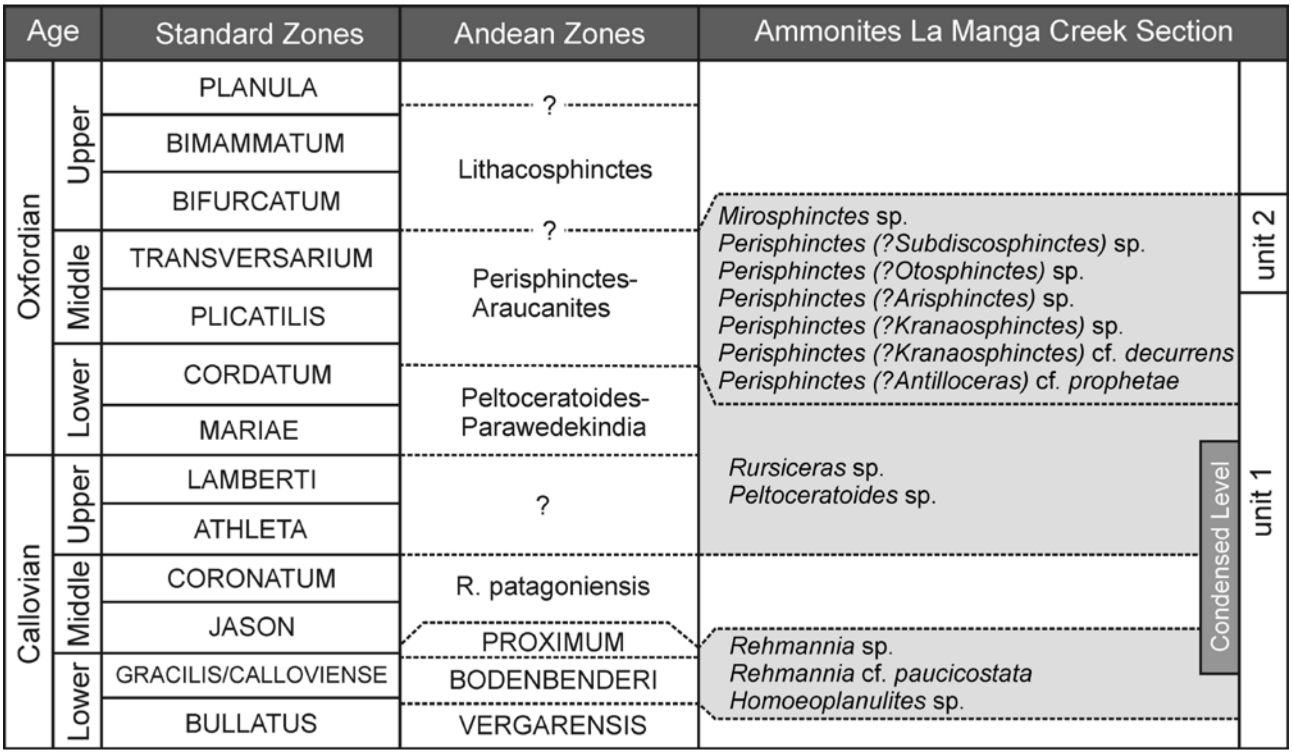

Fig. 6: Callovian-Oxfordian biostratigraphy with a comparison of the Standard Ammonite Zones, Andean Ammonite Zones (after RICCARDI, 2008), and ammonites of the La Manga Creek.

similar vertical succession of facies distribution was recognized in the basin (LEGARRETA & GULISANO, 1989; LEGARRETA, 1991, PALMA *et al*., 2007), nevertheless, local differences on the facies controlled by intra-basinal factors were observed. Previous attempts to establish an assemblage fauna zonation on the basis of ammonites failed due to inadequate collecting technique.

The results reported here allow us to accept that the onset of sedimentation of the La Manga Formation in the Atuel area was Early Callovian. The excellent exposures of this unit in the study area were used to modify the limit of the Lotena Mesosequence. The Lotena Mesosequence, developed from Middle Callovian to Late Oxfordian–Kimmeridgian times, was originally divided into three depositional sequences by LEGARRETA & GULISANO (1989). The boundary of the third depositional sequence was located between La Manga and Auquilco Formations by these authors, but according to the evidence provided in this paper it is possible that this boundary occurs between unit 1 and unit 2 of the La Manga Formation in the Middle Oxfordian, as the result of a forced regression event. A widespread and contemporary palaeokarst surface at the top of La Manga Formation was formed as a consequence of this episode of sudden sea-level fall. This palaeokarst surface occurs in several areas and with varying features. Analysis of these localities allowed us to establish that a sea-level change occurred probably by the end of Middle Oxfordian or Upper Oxfordian, which is very important to take into account for the palaeogeographic reconstructions of the basin.

The results of detailed stratigraphic analysis allowed us to establish new precisions concerning the age and distribution of the ammonite fauna than previously known. According to new detailed sedimentary, stratigraphic and biostratigraphic data, the Lotena Mesosequence could be extended to the Lower Callovian (161.2 ± 4.0 Ma; GRADSTEIN *et al*., 2004). Taking into account the presence of the condensed level, a time of very slow deposition due to sediment starvation is accepted.

This stratigraphic knowledge provides new data about the facies correlation, and thus it should allow reaching more precise palaeoenviromental and palaeogeographical interpretations.

VI. CONCLUSIONS

The integrated data become an important tool for contributing to the biostratigraphic refinement of the sedimentary evolution of the La Manga Formation in the study area, making it possible to extend the age of the Lotena Mesosequence to the Early Callovian on the basis of ammonite faunas.

The La Manga carbonates were deposited on a distally steepened ramp. Outer-ramp facies (unit 1) are characteristic of a low-energy open marine setting affected by sporadic fine-grained turbidite episodes. The presence of a condensed level with several ammonites from the Bodenbenderi-Proximum Zones and *Peltoceratoide*s-*Parawedekindia* Zone allows the assignment of this interval from the upper part of the Lower Callovian to the Upper Callovian and possibly to the Lower Oxfordian. Other ammonite assemblages collected from unit 1 include ammonites of the Middle Oxfordian *Perisphinctes-Araucanites* Zone.

Inner ramp environments (unit 2) were characterized by peritidal shallowing-upward sequences, with stromatolites, breccias, flat-pebble conglomerates, and frequent evidence of subaerial exposure and paleokarst surfaces. The sharp contact between the outer ramp facies of unit 1 and the overlying intertidal-supratidal facies of unit 2 can be interpreted as an abrupt sea-level fall (forced regression).

A widespread palaeokarst surface at the top of the La Manga Formation occurs in several areas. Studies of these localities allowed us to establish that a sea-level change occurred probably by the end of the Middle Oxfordian, although an Upper Oxfordian age cannot be ruled out.

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